Louisiana Coastal Area (LCA), Louisiana

Ecosystem Restoration Study

July 2004

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Appendix D - Louisiana Gulf Shoreline Restoration Report

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LOUISIANA COASTAL AREA (LCA), LOUISIANA

ECOSYSTEM RESTORATION STUDY

APPENDIX D

LOUISIANA GULF SHORELINE RESTORATION REPORT

TABLE OF CONTENTS

List of figures

List of tables

Foreword

This Louisiana Coast-Wide Ecosystem Study (LCA) Report Appendix entitled, "Louisiana Gulf Shoreline Restoration Report" is designed to provide an understanding of the geologic framework and expert opinion on the complex processes that shape Louisiana's Gulf shoreline. Expert science and engineering guidance is provided to help steer the LCA in the successful implementation of projects and programs that will restore Louisiana's Gulf shoreline. After the impact of Tropical Storm Isidore and Hurricane Lili during the 2002 hurricane season, the Louisiana Department of Natural Resources – Office of Coastal Restoration and Management (LDNR) established the Louisiana Gulf Shoreline Restoration Science Advisory Team (Shoreline Restoration Team) to provide the best multidisciplinary science advice, guidance, and expert opinion to support the Coastal Wetland Planning, Protection, and Restoration Act (CWPPRA) of 1990 and LCA activity for Gulf coastal restoration in Louisiana. The Shoreline Restoration Team consisted of scientists from Louisiana and the United States.

Between November 2002 and May 2003, the Shoreline Restoration Team met four times to exchange information and discuss important Gulf coast restoration issues associated with CWPPRA and LCA. LADNR Assistant Secretary Randy Hanchey tasked the Coastal Restoration Team to prepare this LCA Appendix Chapter.

Many colleagues contributed to the preparation of this important document. The members of the Shoreline Restoration Team would like to recognize the support of Secretary Jack Caldwell, Assistant Secretary Randy Hanchey, Gerry Duszynski, Dr. Bill Good, Jon Porthouse, and Dr. Ken Duffy of the LADNR. We would like to also thank Col. Peter Rowan, John Saia, Troy Constance, Howard Gonzales, and Tim Axtman of the USACE.

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CHAPTER D.1
REGIONAL GEOLOGY OF SOUTHERN LOUISIANA

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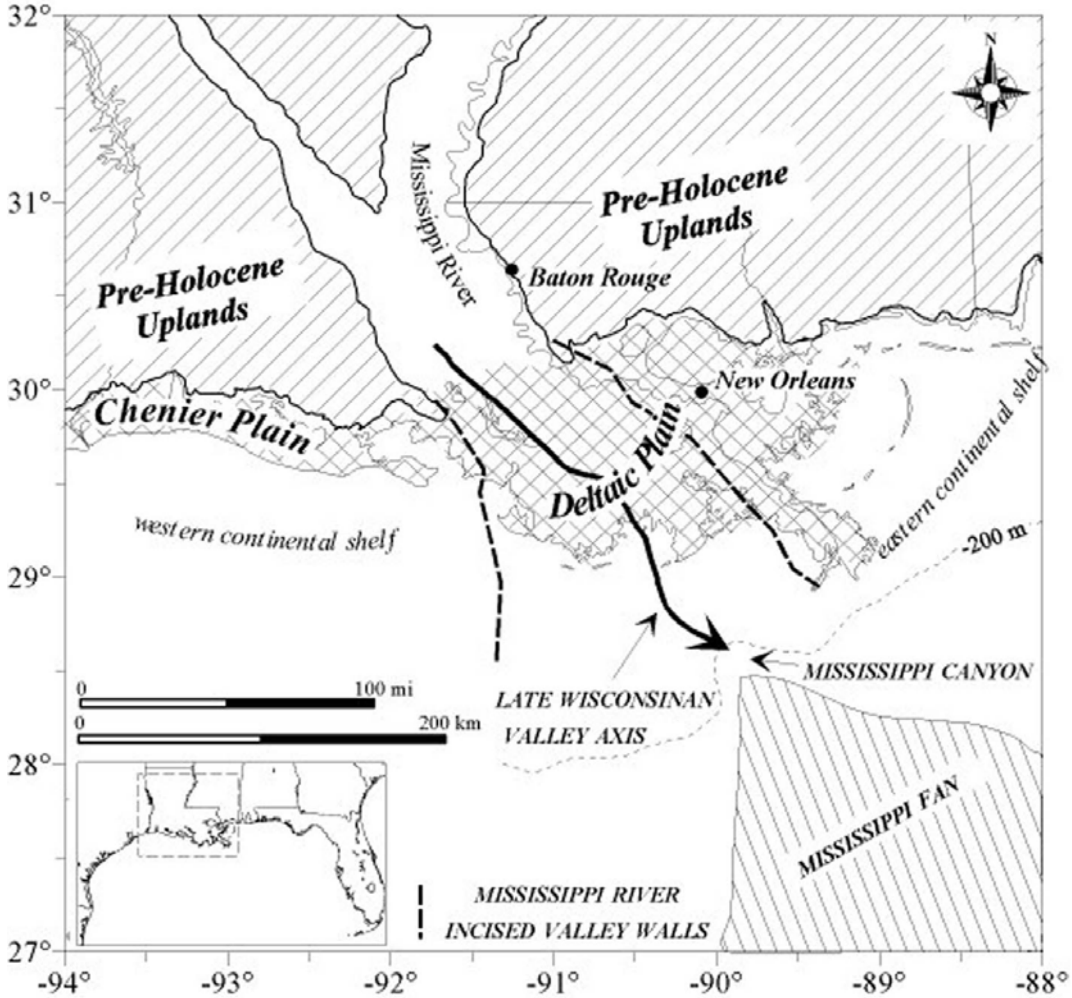
1.1 Summary

This chapter provides an overview of the physiography, structure, stratigraphic framework, and geologic history of southern Louisiana's Mississippi River Delta and Chenier Plain. The intent is to introduce the geologic framework of the region and develop background for topics to be discussed in ensuing chapters. Geologic features and events of the study area, specifically, those of the Holocene (last 10,000 yrs), are given the most emphasis. However, an adequate understanding of contemporary geology is not possible without addressing some regional geologic features and older geologic events.

1.2 Introduction

The north-central Gulf of Mexico basin has been the site of deposition by large fluvial systems since at least the Late Jurassic (~ 150 million years before present (ybp); Mann and Thomas 1968). Since the Late Jurassic, a sedimentary succession in excess of 6 mi thick (10 km thick), deposited in fluvial, deltaic, and marine environments, has accumulated. Through switching sites of major depocenters and progradational outbuilding, the north-central Gulf of Mexico margin has changed considerably. The northern margin of the Gulf basin continues to be the site of major deltaic deposition. Today, the basin receives approximately 6.1 million tons (5.4 million t) of sediment annually from North America's largest drainage basin of more than 1.2 million mi2 (3.2 million km2). The trunk distributary of this drainage system is the Mississippi River. During the Holocene, the river constructed the Mississippi River Deltaic Plain, one of the world's largest delta plains in excess of 11,500 mi2 (30,000 km2) (Coleman et al. 1998). The Deltaic Plain consists of a generally fine-grained sedimentary package deposited within a wide variety of fluvial, deltaic, and coastal depositional environments. Toward the west, the Deltaic Plain merges with the Louisiana Chenier Plain, an approximately 125-mi long by 12 mi (200-km long by 20-km) coastal plain consisting of sand and shell ridges separated and underlain by mud-rich sediments. The Chenier Plain was formed by processes distinctly different from those responsible for the formation of the fluvial-dominated Deltaic Plain (Figure D.1- 1; Gould and McFarlan 1959; Penland and Suter 1989). Consequently, the Chenier Plain constitutes a physiographic province that, although related to and influenced by Deltaic Plain processes, is geomorphologically and sedimentologically distinct. The following sections provide a chronologic framework for the formation of the north-central Gulf Basin.



The Mississippi River has, during the Holocene, been confined to an alluvial valley bordered by Pleistocene and older sedimentary units (Pre-Holocene Uplands). Also during the Holocene, the Mississippi River Delta has shifted laterally across the upper continental shelf and constructed a delta plain of more than 30,000 km2 (Coleman et al. 1998). Coast-parallel outcrops of pre-Holocene sedimentary units form the northern boundary of the Deltaic and Chenier Plains. The pre-Holocene units dip basinward below the Deltaic and Chenier Plains and are progressively older to the north, perpendicular to their coast-parallel trends (Autin et al. 1991). During the late Wisconsin sea-level lowstand, the Mississippi River extended across the sub-aerially exposed continental shelf (Fisk 1944; McFarlan and LeRoy 1988) delivering sediment to the Mississippi Fan through the Mississippi Canyon (Coleman et al. 1983). The Deltaic and Chenier Plains represent the sub-aerial part of a sedimentary mass deposited by fluvial, deltaic, and marine processes since late Wisconsin sea-level lowstand approximately 18,000 ybp (C0oleman et al. 1991). The Chenier Plain, located to the west of the Deltaic Plain, consists of topographically high, sand-rich ridges separated by lower elevation mudflats. Mudflats are progradational in origin, formed by westward-directed longshore drift that transported fine-grained sediment from deltaic depocenters located farther east.

Figure D.1-1. Map of study area showing the Mississippi River Delta region of the north-central Gulf of Mexico.

1.3 Creation and Evolution of the North-Central Gulf of Mexico Basin

The Gulf of Mexico Basin includes south Louisiana. This region was formed by a complex series of geologic processes that began tens of millions of years ago. Within the last 20,000 years, the main landscape-shaping processes have been sediment deposition by the Mississippi River and sea level rise and stabilization.

The Gulf of Mexico Basin is an elliptical, semi-enclosed, depositional basin with a northeast-southwest long axis, bordered by the southern margin of North America and eastern margin of Central America (Figure D.1-1). Open-marine communication is to the Atlantic Ocean between the Yucatan and Florida peninsulas that rim the Gulf Basin on the south and east, respectively.

Formation of the Gulf Basin and its evolution toward a configuration resembling that of today is largely attributed to Late Triassic events initiated by plate tectonics, specifically the break up of Pangea (Salvador 1991). Separation of North America from the African and South American part of Pangea created an extensive network of fault-bounded basins along the southern margin of North America. These basins opened through the early Mesozoic to create the Gulf Basin. Tectonic stability has characterized the basin since the Late Jurassic and led to the development of stable continental shelves and ramps along the basin margins (Salvador 1987). Mesozoic rifting is the most recent plate tectonic event to have affected the Gulf Basin. Subsequent modification of the Mesozoic framework has primarily resulted from accumulation of thick sedimentary successions and basinward outbuilding (progradation) of the post-rift basin margins. Along the north-central basin margin, progradation of Cenozoic depocenters extended the northern margin of the Mesozoic Basin as much as 180 mi (300 km) toward the south.

The result of abundant Cenozoic sediment supply, changing sea level, and migrating depocenters was the deposition of thick clastic sedimentary wedges along the north central basin shelf and slope. The wedges were formed in stacked, imbricated, offlapping depositional packages. Cenozoic sediment thickness is as much as 6 mi (10 km) near the modern Mississippi River depocenter (Galloway et al. 1991). The Cenozoic stratigraphy along the north-central Gulf Basin consists predominantly of interbedded shales, siltstones, and sandstones, deposited in a continuum of shallow shelf to deeper water off-shelf depositional environments.

North-central Gulf Basin depositional patterns during the Quaternary (a subdivision of the Cenozoic) were most strongly influenced by the repeated rise and fall of sea level in response to the growth and decay of Quaternary ice sheets at high latitudes. Along the northern perimeter of the modern Louisiana coastal plain, evidence of these repeated fluctuations in sea level are recorded in successively older, and structurally elevated-to-the-north, “terraces” that dip seaward below Holocene sediments. These sedimentary packages and older units are referred to as pre-Holocene uplands on Figure D.1-1. The more recent Holocene sediments of the Mississippi River Deltaic Plain rest on this foundation.

The most recent lowstand of sea-level elevation occurred during a maximum glacial advance approximately 18,000 ybp (late Wisconsin glacial maximum). Estimates for the elevation of the late Wisconsin sea-level lowstand range between -291 ft and -512 ft (-91 m and -160 m) below modern sea level (Fisk and McFarlan 1955; Curray 1960; Frazier 1974; Suter et al. 1987); however, a –384 ft (-120 m) elevation at 18,000 ybp is generally accepted (Fairbanks 1989; Saucier 1994). Across the outer Louisiana shelf, numerous shelf-edge deltaic intervals formed during the late Wisconsin phase of falling and low sea level (Suter and Berryhill 1985; Kindinger 1988; Sydow and Roberts 1996). Detailed mapping of these shelf-edge deltaic packages using seismic profile data indicates that progradation of the deltaic packages toward the Pleistocene shelf edge was concomitant with landward erosional truncation and incision of underlying previously deposited sediments as the shoreline shifted basinward approximately 100 mi (~160 km) with the sea-level fall. In areas of minimal incision, this unconformity is preserved in the subsurface as a highly weathered and oxidized surface that resulted from sub-aerial exposure and leaching and has variously been referred to as the Prairie surface or late Wisconsin unconformity (Fisk 1944; Stanley and Warne 1994; Kulp et al. 2002). Fisk and McFarlan (1955) referred to this weathered horizon as the "Prairie surface" because of suggested updip correlation to a coast-parallel outcrop of the late Pleistocene Prairie Formation.

The most prominent late Wisconsin incision was formed as the Mississippi River alluvial valley extended to the shelf edge at the head of the Mississippi Canyon (Figure D.1-1). At the modern coastline, depth to the base of the excavated alluvial valley is approximately 320 ft (100 m). During this sea-level lowstand, much of the river's sedimentary load was funneled through the Mississippi Canyon to the Mississippi Fan (Figure D.1-1; Coleman et al. 1983). Between 18,000 and 12,000 ybp, delivery of sediments to the shelf edge diminished as sea level rose quickly in response to late Wisconsin deglaciation. Continued sea-level rise and initial flooding of incised valleys created estuaries that favored deposition of fine-grained, organic-rich sediment (Coleman et al. 1983). Relatively coarser-grained, braided fluvial systems that developed during lowstand conditions adjusted to the subsequent sea-level rise by evolving toward meandering regimes (Coleman et al. 1991). As sea-level rose and estuaries flooded, backswamp and floodplain environments developed and deposition within these topographically low areas was enhanced (Kulp et al. 2002). This deposition is recorded in the upward-fining grain size of the relatively coarser-grained substratum interval that fills the zones of late Wisconsin incision. Organic-rich sediments of brackish/estuarine origin above coarse-grained, channel-fill sediments typically indicate initial drowning and inception of estuarine environments within the stream valleys flooded by rising sea level (Suter et al. 1987; Sydow and Roberts 1996). This initial flooding marks a major change in depositional style, generally recorded in the incised valleys as a vertical gradation from gravelly sand sediments to more organic-rich, finer-grained strata. Fisk (1944) referred to the generally fine-grained unit above substratum and interfluves as topstratum. The topstratum sediments record marine, deltaic, and low-gradient fluvial deposition within formerly incised valleys, as well as on the continental shelf (e.g. Fisk and McClelland 1959). Approximately 12,000 to 10,000 ybp, rates of sea-level rise had slowed enough to allow the Mississippi River to begin prograding outward from the confines of the southern terminus of the alluvial valley onto the bordering continental shelf and begin forming the Mississippi River Deltaic and Chenier Plains of southern Louisiana.

1.4 Holocene Evolution and Physiographic Provinces

1.4.1 Formation of the Deltaic and Chenier Plains

The Holocene geologic framework and history of the Mississippi River Deltaic Plain and bordering Chenier Plain have been determined from more than 30,000 borings, high-resolution seismic reflection profiles, and hundreds of radiocarbon age determinations. Current depositional models describe the Holocene history of the Mississippi River Delta as a dynamic, multi-stage process that reflects the complex interplay between changing rates of sea-level rise and sediment fluvial dispersal pathways (Frazier 1967; Penland et al. 1988; Boyd et al. 1989). The Holocene sedimentary package contains depositional units that have developed as a result of deltaic progradation and abandonment, resulting in an assemblage of overlapping, stacked units of unconsolidated sands and muddy sediments. Growth and abandonment of these deltas are responsible for the formation of the Deltaic Plain in the central and southeastern portions of coastal Louisiana and contributed directly to the formation of the Chenier Plain to the west (Figures 1).

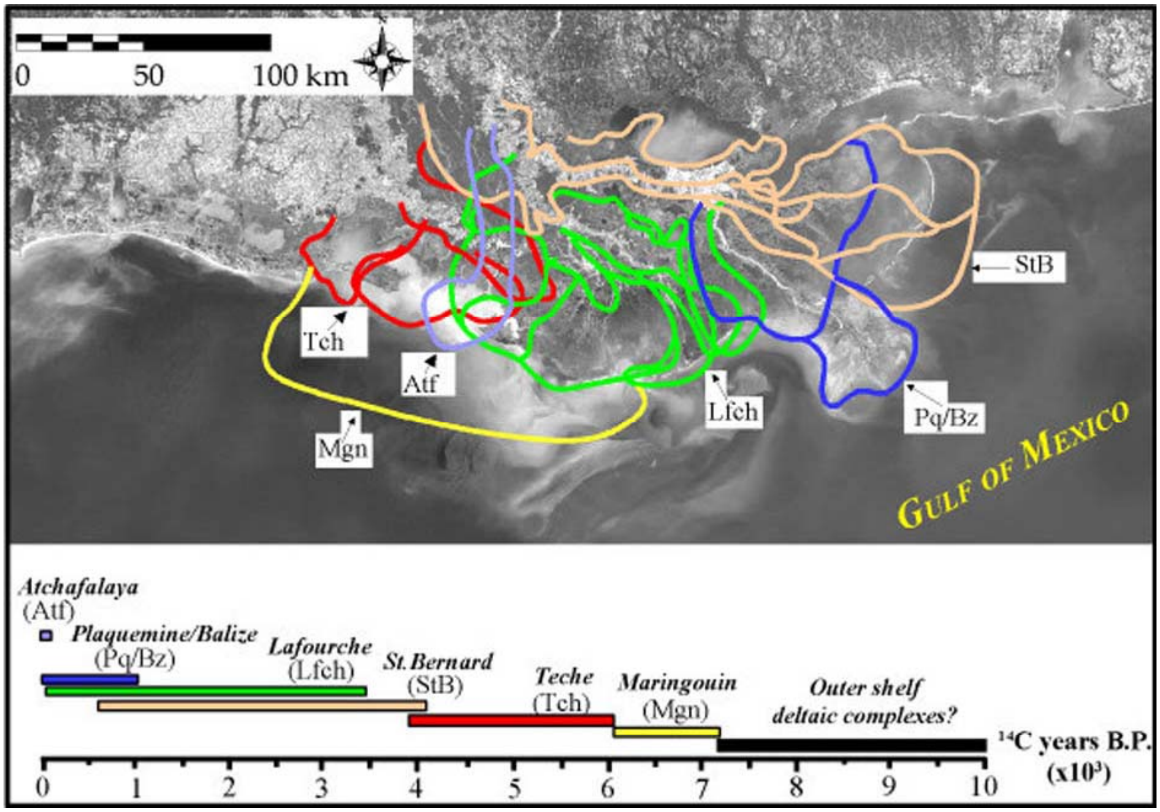
1.4.2 Deltaic Plain

South Louisiana consists primarily of sediments deposited by the Mississippi River as it emptied into the Gulf of Mexico over the last 10,000 years. The river has altered its course many times, causing mud-rich sediment to be accumulated in a variety of locations across south Louisiana and creating the modern Mississippi River Deltaic Plain.

The modern Mississippi River Deltaic Plain consists of two active (Balize and Atchafalaya depocenters) and several inactive deltaic complexes (Figure D.1-2). Each time the Mississippi River has built a major delta lobe seaward at the front of a seaward advancing distributary network (regressive deposition), it has subsequently been abandoned in favor of a shorter, more direct route to the sea. Changes in distributary courses and the accompanying shifts in sites of deposition have resulted in the geographic distribution of deltaic sediments along the coast of southeast Louisiana. Soon after a delta lobe is abandoned, marine inundation and reworking of the delta (transgression) begin as a result of decreased sediment supply and substrate subsidence. Individual deltaic complexes generally undergo a regressive phase of deposition that lasts approximately 1,000 to 2,000 years. These alternating cycles of regression and transgression, driven by delta lobe growth and lobe abandonment and marine reworking respectively, have been termed the delta cycle (Figure D.1-3) (Scruton 1960; Roberts, 1997). The delta cycle has been of fundamental importance to the construction of the southern Louisiana fluvial, deltaic, and barrier shoreline environments and landscape.

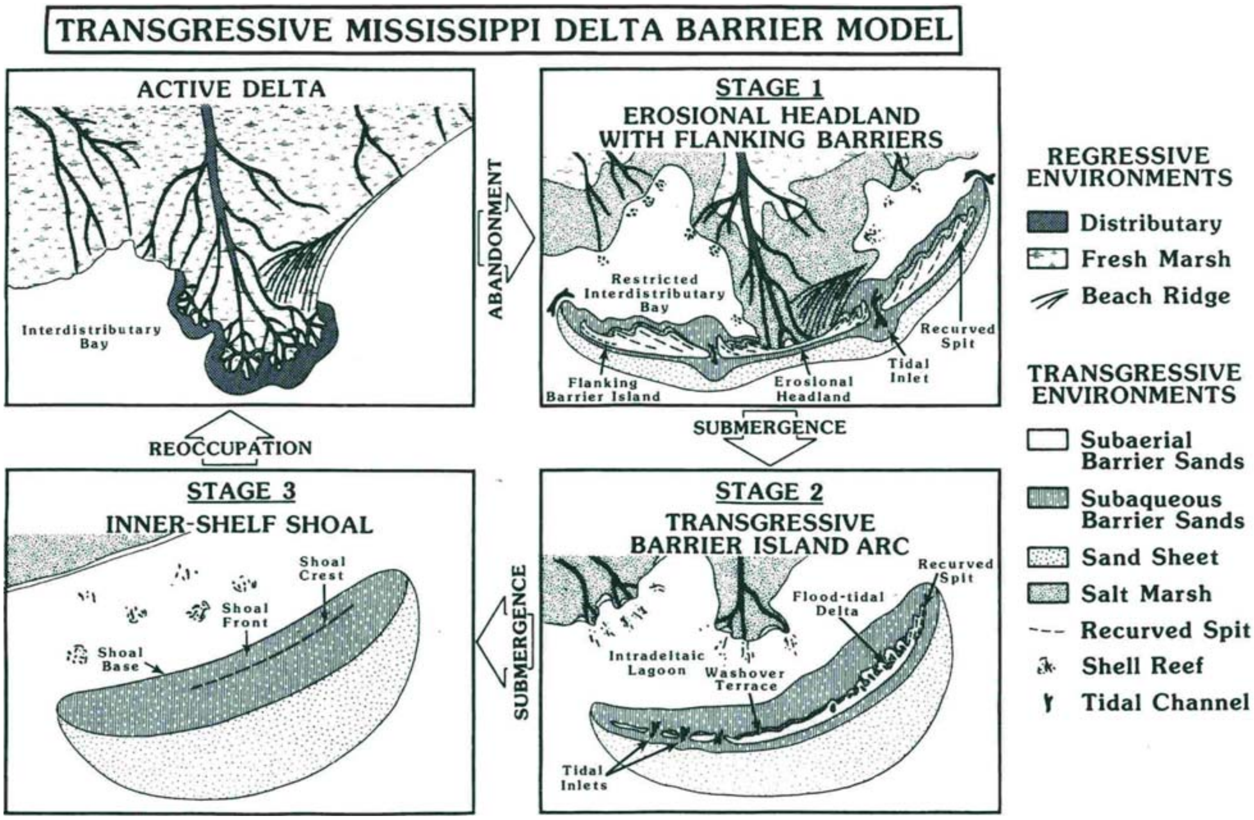
Regressive Episodes

Regressive deposition is recognized as an important process contributing to the vertically stacked and laterally offset deltaic depocenters that are preserved within the shallow Holocene stratigraphic framework of the Mississippi River Deltaic Plain and adjacent continental shelf (e.g. Scruton 1960; Coleman and Gagliano 1966; Frazier 1967). Regressive depositional episodes are characterized by the seaward advance of distributaries, resulting in the construction of deltaic headlands and a progressively more seaward coastline. During regressive sedimentation, prodeltaic sediments at the head of the advancing deltaic front form a mud-rich platform across which the distributaries advance. This process results in a progressively coarsening upward sedimentary unit that typifies deltaic progradation. Moreover, during deltaic progradations, wetlands fringing the deltaic front and distributary network expand laterally, creating a landscape dominated by fluvial pathways, wetlands, and bays between active distributary networks. Distributaries are, however, ephemeral; seaward progradation results in lengthened distributary networks, a reduction in their gradient, and ultimately, abandonment of the active distributary networks in favor of shorter, more hydraulically efficient routes. Distributary switching is a naturally occurring event and a fundamental process that has contributed to the overall geomorphology and architecture of the Holocene Mississippi River deltaic sediments.



By at least 10,000 ybp deltaic sequences were being constructed on the upper shelf during times of relative sea-level stability in the overall rising sea level (Boyd et al. 1989). Following sea-level highstand at approximately 4,000 ybp, deltaic progradation switched to the east, migrating through distributary switching processes to the west and eventually to the modern Birdfoot Delta (Balize depocenter). Net result of the migrating depocenters is a vertically stacked and offset sedimentary package of primarily deltaic deposits that have created the extensive fluvial networks and wetlands of southern Louisiana. Following abandonment of individual delta lobes the deltaic depocenters became submerged and reworked by marine processes. The depocenters then formed transgressive coastlines, barrier island systems, and ultimately submerged sand shoals on the continental shelf. Chronology and distribution of deltaic complexes modified from Frazier (1967).

Figure D.1-2 Geographic distribution and chronology of Holocene Mississippi River delta



Abandoned erosional headlands built by seaward-advancing delta lobes are subject to marine reworking, resulting in transgression and their ultimate transformation to a inner-shelf, sand-rich shoal (from Penland et al. 1988).

Figure D.1-3. Three-stage conceptual model detailing the genesis and evolution of transgressive depositional systems along the Mississippi River Deltaic Plain

Since the seminal work of Fisk (1944), in which he recognized six delta complexes consisting of smaller subdeltas or delta lobes, several chronologic frameworks for the Holocene Mississippi River deltaic deposits have been suggested (e.g. Kolb and Van Lopik 1966; Frazier 1967), although Frazier's (1967) model appears to be most widely accepted. Using a large database of borings and radiocarbon dates, Frazier (1967) identified five delta complexes and a total of 16 delta lobes that are characteristically lobate in shape. A delta complex represents the sedimentary package deposited by all of the smaller delta lobes that are tied to a common distributary. From oldest to youngest, the delta complexes are: the Maringouin, Teche, St. Bernard, Lafourche, and Plaquemine-Balize (Figure D.1-2). Dates highlighting the age of the deltaic depocenters have been derived from radiocarbon-dated deposits (e.g. McFarlan 1961; Frazier 1967; Tornqvist et al. 1996) as well as archeological evidence (McIntire 1954). The timing of distributary switching to produce the lateral offset of each delta complex are not yet fully understood, but apparently the latter three deltaic complexes shared distributary flow at times. Recently Penland and others (1988) recognized above Maringouin and Teche deposits a laterally extensive marine ravinement surface that probably formed during an absolute sea-level rise. Thus, the Maringouin-Teche complexes constitute an early Holocene delta plain constructed during a time of relatively stable sea level. Subsequent sea-level rise reworked and truncated these early deltaic deposits and created a ravinement across which subsequent deltaic complexes prograded to form the most recent deltaic plain. Except for the modern Plaquemine/Balize deposition located at the shelf edge, the Holocene Deltas were restricted to shallow inner-shelf waters as indicated by their relatively thin (30 ft to 100-ft thick; 10 to 30-m thick) but geographically extensive coverage (as much as 5,400 mi2; 15,000 km2). In contrast, the Plaquemine/Balize shelf-edge package is geographically restricted but consists of an interval of progradational sediments nearly 320-ft thick (100-m) (Kulp et al. 2002).

Transgressive Episodes

Distributary abandonment, coupled with the combined effects of substrate subsidence and absolute sea-level rise results in erosional headland retreat and the landward migration of the shoreline as sediment is reworked and redistributed by marine processes. As the headlands are subjected to wave and storm erosion during a period of diminishing or non-existent sediment supply, the sediment comprising the headland is dispersed laterally and contributes to the construction and nourishment of flanking beaches, beach ridges, and chenier plains. Penland and others (1988) emphasized the significance of headland reworking and transgressive events in the stratigraphic architecture of the deltaic system, through a conceptual model that accounts for the genesis of transgressive stratigraphy. Their three-stage model depicts the evolution of an active deltaic headland to an inner-shelf shoal through processes of marine reworking and relative sea-level rise (Figure D.1-3).

Transgressive deposition begins when marine processes transform an abandoned deltaic depocenter into an erosional headland with flanking headland barriers and re-curved spits built by longshore transport of headland sand sources (Stage 1). Limited sediment supply from the abandoned distributaries coupled with continued relative sea-level rise and shoreface erosion eventually leads to detachment of the stage-1 barrier shoreline from the mainland and formation of a stage-2, barrier-island arc. The final stage occurs during transgressive submergence when the ongoing relative sea-level rise and storm processes rework the barrier island arc sediment and convert it to a sand-rich marine shoal that is separated from the deltaic coastline, ultimately becoming isolated on the inner shelf (Figure D.1-3). This three-stage model explains the overall distribution of active and abandoned fluvial networks on the Deltaic Plain as well as the distribution and relationship of shorelines and barrier island systems that fringe the southern Louisiana coast. The phases of regression and transgression that the Deltaic Plain has undergone during its evolution have been conceptualized within the delta cycle model (Figure D.1-4).

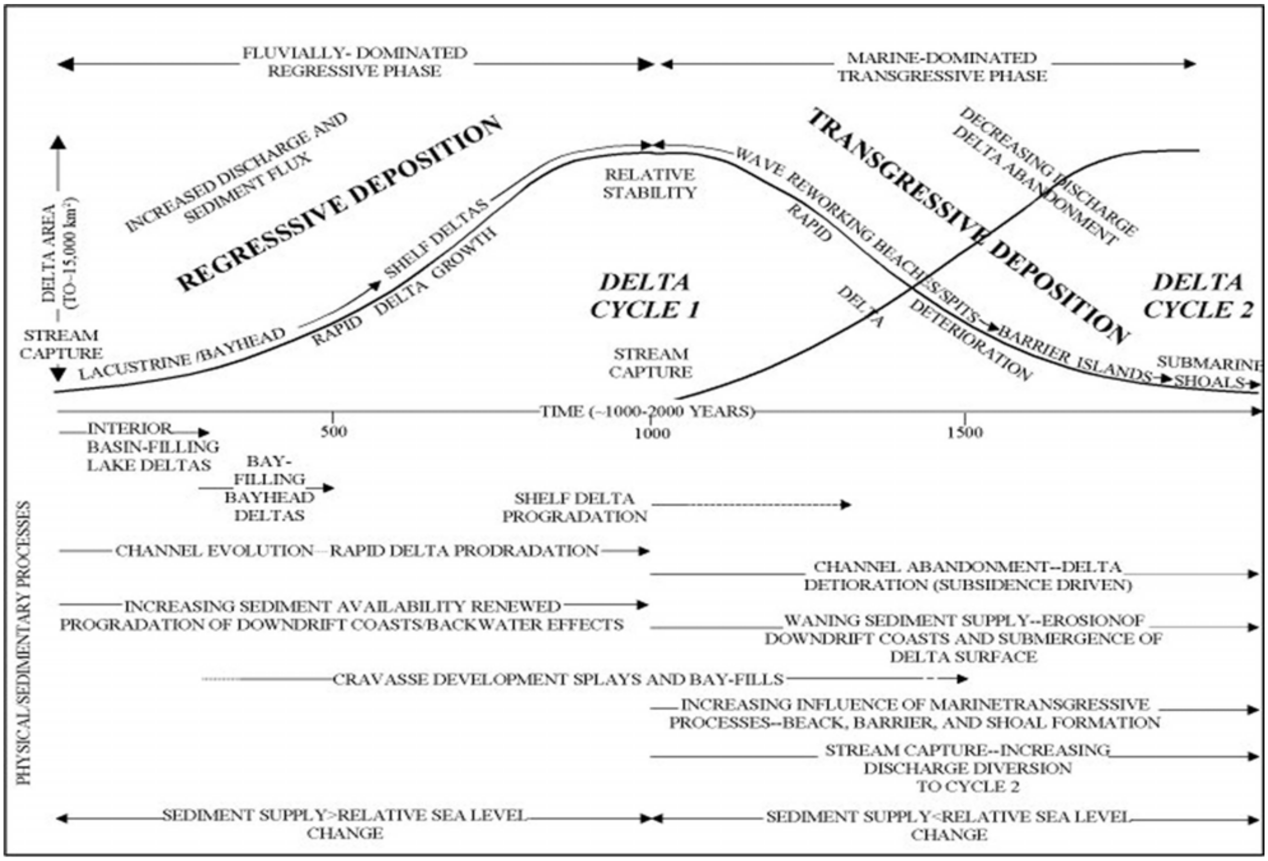
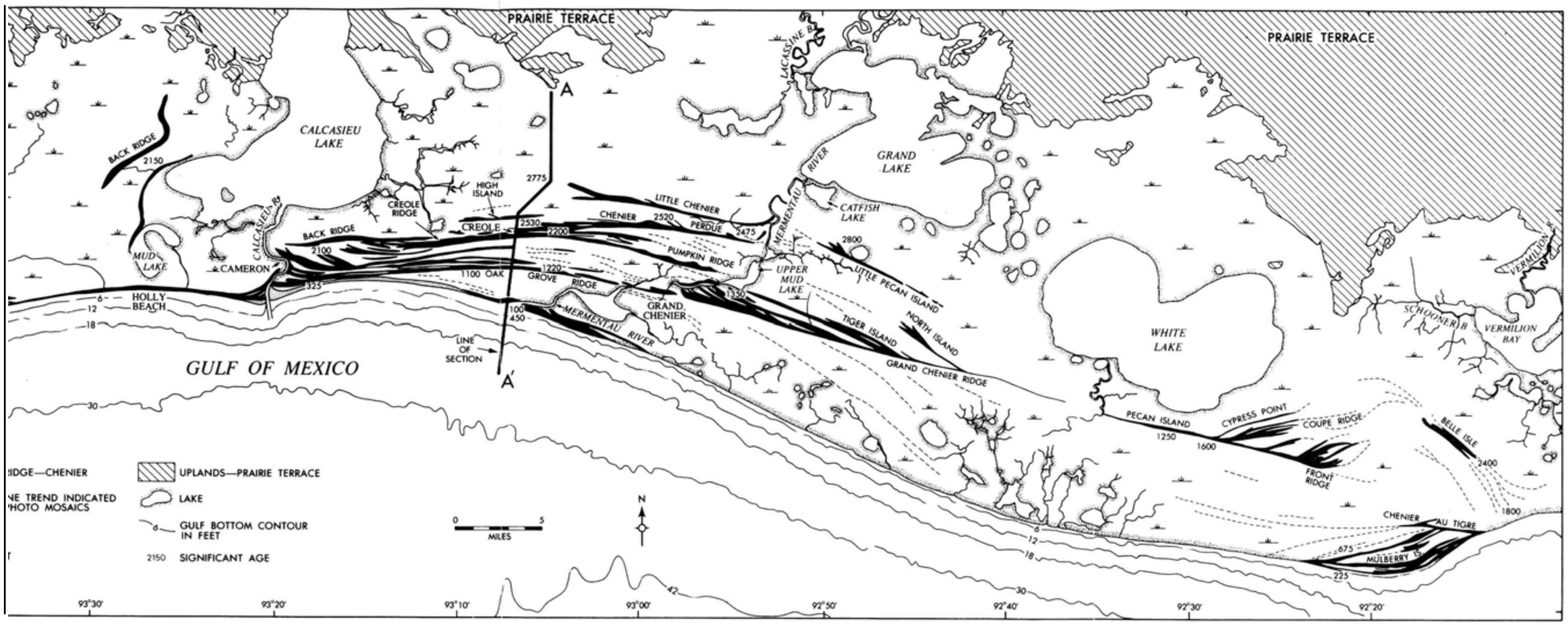


Figure D.1-4. Graph of the delta cycle showing the growth and decay of individual delta lobes through processes of fluvial switching and relative sea level rise (from Roberts 1997).

1.4.3 Chenier Plain

The Chenier Plain was formed by different processes than the Deltaic Plain. Some river sediments were carried west by currents, where they accumulated in broad areas called mudflats. After years of exposure to waves and currents, the mudflats were eventually molded into sandy ridges located parallel to the shore. Oak trees ("cheniers" in French) grew on these ridges and gave the region its name.

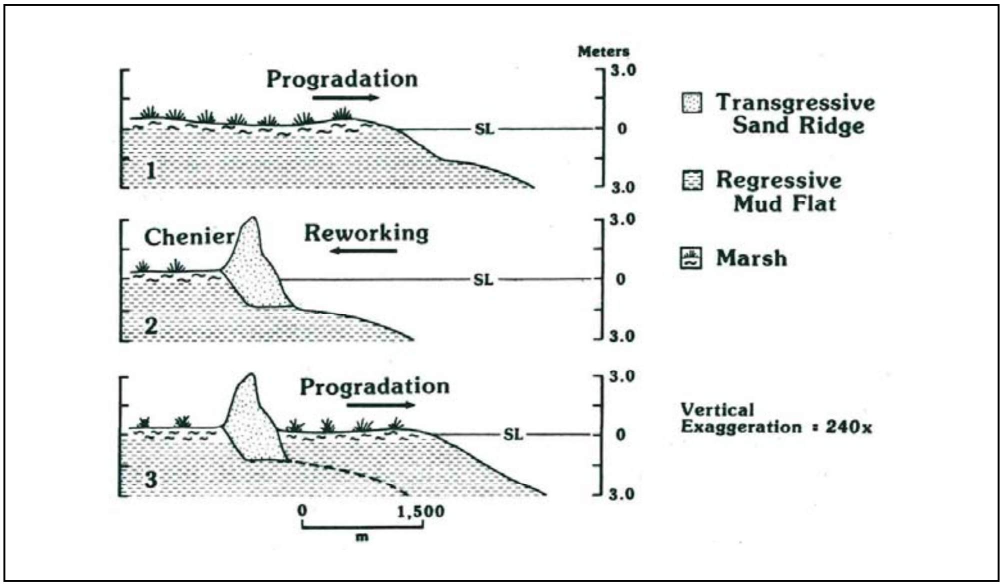
A chenier plain consists of multiple shore parallel, sand-rich ridges that are perched on and physically separated from one another by relatively finer-grained, clay rich sediments (Figure D.1-5). The Chenier Plain of southwestern Louisiana extends from Sabine Pass, Texas to Southwest Point Louisiana, with elevations of approximately 6 to 20 ft (2 to 6 m). The Chenier Plain evolved during the Holocene as a sequence of progradational mudflats that were intermittently reworked into sandy or shelly ridges to form the modern physiography. Numerous cycles of deposition and erosion created alternating ridges separated by marshlands. Sediment of the Chenier Plain has been primarily supplied by longshore transport of fine-grained Mississippi River sediments west of the Deltaic Plain. These sediments, transported by westward flowing nearshore currents, were eventually deposited along the chenier shoreline as mudflats that built seaward with continued sediment supply. When deposition ceased or declined due to a shift in



Note the shore parallel distribution of sandy ridges separated by ridge-elongate mud flats and marshlands. Ages on ridges indicate their radiometrically-determined times of formation (by Gould and McFarlan 1959)

Figure D.1-5. Regional geomorphologic framework of the southwestern Louisiana Chenier Plain.

Mississippi River Delta depocenters on the east, the previously deposited mud-rich sediment was reworked by coastal processes. These processes concentrated the coarse grained sediments and formed shore-parallel ridges called "cheniers" (Gould and McFarlan 1959; Byrne et al. 1959). Introduction of new sediment by westward shifts of the Mississippi River Delta resulted in the isolation of these ridges by accretion of new material on the existing shoreline (Figure D.1-6). Thus, repeated seaward growth and retreat along the Chenier Plain is a consequence of deltaic deposition farther east as well as the periodic cessation of sediment supply to the Chenier Plain as deltaic depocenters were abandoned. Currently, the Atchafalaya River is supplying the Chenier Plain with fine sediments by westward-directed longshore transport of fine-grained material.



. Stage 1 is characterized by mudflat progradation as updrift deltaic lobes prograde seaward and fine-grained sediment at the advancing deltaic front is transported downdrift and accreted along the Chenier Plain, resulting in mudflat progradation. During Stage 2, sediment supply is curtailed as updrift delta lobes are abandoned for other less mature and perhaps more distally located distributaries and delta lobes. As a result, the shoreline is subject to reworking by marine processes. Fine-grained sediment is winnowed from the shoreline, leaving a relatively coarser-grained sand-rich chenier ridge. Renewed progradation of the mudflats occurs as delta lobes begin again to supply fine-grained material to the downdrift Chenier Plain. Because the growth of delta lobes on the Deltaic Plain strongly influences the timing and magnitude of chenier plain progradation and reworking, the growth of the Chenier Plain is very closely tied to the delta cycle and switching model (by Penland and Suter 1989).

Figure D.1-6. Conceptual diagram showing the processes contributing to the construction of the southwestern Louisiana Chenier Plain

1.5 Conclusion

The surface and subsurface geology of the Mississippi Delta region is the byproduct of a complex and varied history related to fluvial, deltaic, and marine sedimentary processes. These processes are influenced by sea-level variations as well as large-scale plate tectonic events. Within the last 10,000 years (Holocene epoch), deposition within a wide variety of fluvial, deltaic, and coastal environments has contributed to the construction of a generally fine-grained sedimentary package that forms the contemporary Mississippi River Deltaic Plain, wetlands, and fringing barrier island systems. West of the Deltaic Plain are the physiographically distinct sand-rich ridges and mudflats of the Louisiana Chenier Plain. Although the Deltaic Plain provided the sediments that built the Chenier Plain, the cheniers were created by different processes than those that govern the fluvial-dominated Delta. The region's geology is complex, but the fundamentals of geologic evolution are reasonably well understood, providing a solid foundation for understanding the processes of coastal change and wetland loss in Louisiana.